The Potential of Dynamic Segmentation for Aquatic Ecosystem Management: Pacific Lamprey Decline in the Native Lands of the Confederated Tribes of Siletz Indians (Oregon, USA)*

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A manuscript based on the original M.S. thesis

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Abstract
The Lamprey Eel Decline project conducted by the Confederated Tribes of Siletz Indians (CTSI) combined traditional ecological knowledge, scientific research and geographic information science. CTSI wanted to learn why the Pacific lamprey (*Lampetra tridentata*), a culturally and ecologically important species, was declining in the streams within their native land area. The project included interviewing native elders, characterizing stream habitat, monitoring water quality, creating a geographic information system (GIS) and educating tribal members on the cultural and ecological importance of the Pacific lamprey. Dynamic segmentation, a GIS data structure, was used to link standard stream survey data on the river unit scale to a base stream coverage (1:24,000). Dynamic segmentation efficiently associates georeferenced data to a linear feature, thus allowing the data to be readily assessable on desktop computer systems. To be more useful to the tribal and local resource managers, it is recommended that these GIS coverages of aquatic habitat should be used in conjunction with additional data coverages and basic regional models for watershed analysis and better management of aquatic ecosystems. **Key words: traditional ecological knowledge, Native Americans, dynamic segmentation, data structures, western Oregon**

Introduction

The use of geographic information systems (GIS) as a management tool is becoming increasingly popular with resource managers. GIS are now well known for their ability to display, store and analyze spatial data. The decision-making process in natural resources lends itself well to the use of a GIS because the data are inherently spatial and models exist for ecosystem processes. Historically, the focus has been on descriptive mapping (inventory). However, as GIS becomes more powerful this focus has shifted to prescriptive mapping (analysis) as decision-making becomes increasingly more quantitative (Berry and Ripple 1994).

Wide, planar terrestrial systems are logical fodder for GIS because they are fairly well represented by raster cells or polygons. However, riverine systems pose a unique challenge because they do not generally cover wide areas on the ground, and are better represented using lines. Riverine systems may have many ecological attributes over a short distance, making them more challenging to associate to features. A relatively new data structure, dynamic segmentation, can be used to associate attributes with linear features (ESRI 1994). The Lamprey Eel Decline (LED) project begun by the Confederated Tribes of the Siletz Indians (CTSI) is a prime example of the application of dynamic segmentation to natural resource management. The LED project combines traditional ecological knowledge (TEK; i.e., tribal interviews), wildlife biology (compilation of biological and ecological requirements of the Pacific lamprey), habitat assessment (aquatic habitat survey data from Rock Creek, Oregon) and a GIS (using dynamic segmentation) to address resource management questions, such as reasons for the decline of the lamprey, what should be done to reverse the trend, and where should restoration sites be located.

In 1994, CTSI conducted interviews of tribal elders which were reported in Downey et al. (1996). The interviews documented a recent population decline of the Pacific lamprey in creeks on historically tribal lands. The Pacific lamprey is an anadromous, jawless vertebrate that is native to Pacific Northwest coastal streams. The lamprey was used by local tribes for food, ceremonial and medicinal purposes. CTSI tribal elders voiced concern that they were losing part of their cultural heritage and that the tribe should focus on restoring lamprey populations. In addition to serving as a guide for further research, these interviews provided valuable background information on the local lamprey populations. The completion of the interviews led to the LED project, which investigated factors of the lamprey decline in Rock Creek and Little Rock Creek of the Siletz River basin, Oregon (Figure 1).

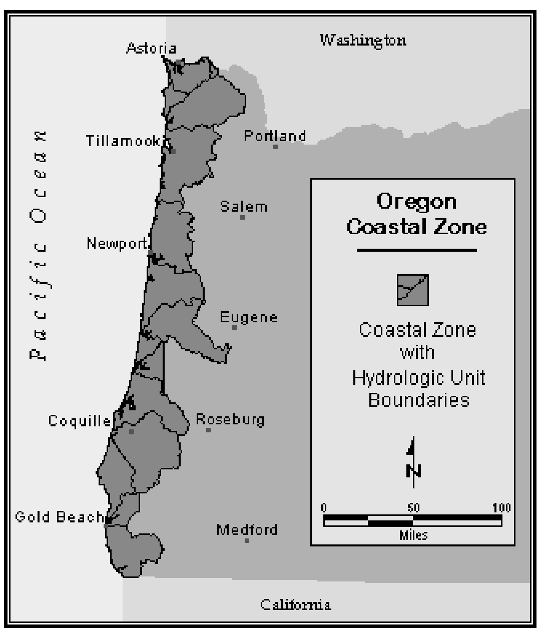


Figure 1: Map of Oregon coastal hydrologic unit boundaries (courtesy of R. Dana, Oregon Department of Land Conservation and Development).

The LED project focused on the Rock Creek watershed, located within the historical land base of the CTSI and on the Pacific lamprey, a traditional food source for the tribe. The LED was designed to address the following issues: causal factors of the lamprey population decline, healthy ecosystem requirements for the lamprey, design of a GIS for sustainable ecosystem management, and cultural and environmental education for tribal members. The project was unique in that it integrated TEK with scientific research and modern-day GIS technology to understand the plight of the lamprey and make sound resource management decisions.

Before its decline, the lamprey was an important part of the Siletz Indian lifestyle. The lamprey is a high-energy food, packed with vitamins and minerals with four times the caloric value per weight of salmon (Whyte et al. 1983). Additionally, Pacific Northwest Native American tribes use the lamprey and its components for medicinal and ceremonial purposes (Close et al. 1995). The lamprey, just as any other native animal species, plays an important role in Pacific Northwest ecology. For example, pinnipeds (seals and sea lions) feeding in the Rogue River estuary, Oregon eat lamprey in larger quantities than salmon when available (Roffe and Mate 1984). CTSI members consider the population decline of the lamprey to be an indicator of greater ecological problems in their native region.

This paper describes the following contributions to the completed LED project: methods of data collection (TEK, wildlife biology, habitat surveys) and the creation of dynamic segmentation within the GIS. A further step, spatial analysis or modeling, is addressed by reviewing the types of ecological modeling available to the resource managers. And finally, suggestions for the expansion and improvement of the current database to create a more holistic description of the aquatic system and its surrounding land base are presented. Limitations of the data require the resource manager to understand GIS and make cautious inferences. Even so, a GIS still provides a valuable means for utilizing available spatial data to make resource management decisions.

The Use of Traditional Ecological Knowledge

Cajete (1994, 1997) describes the foundations for traditional ecological knowledge from the viewpoint of the indigenous learner. These elements exemplify the complex and holistic nature of knowledge held by native peoples. Since these cultures do not have a literate base, their teaching and learning styles are based on stories, which keep the continuum of knowledge alive. The stories or teachings have an environmental foundation based on the community's relationship with the land, and adapt as that relationship changes. There is an artistic or visionary component, which deepens the understanding of those relationships. This "spiritual ecology" recognizes "all life is imbued with an animating energy to which we are all connected" (Cajete 1997). This holistic, experience-based knowledge, which has inherent historical information, is vital to the survival of a tribe.

The Inuit explain TEK as “a way of life, based on the experience of the individual and the community, as well as knowledge passed down from one’s elders and incorporated in indigenous languages. This knowledge is constantly being adapted to the changing environment of each community and will remain current as long as people still use the land and sea and their resources” (ICC 1996). TEK includes the acquisition of ecological information, as well as the understanding and the practice of ecological principles. Often, only the "convenient" aspects of TEK are incorporated into western science and the holistic nature of the knowledge is lost. Because of this, a lack of mutual respect between parties can result in a failed attempt to combine the two methods of environmental research. However, this respect is critical for the success of any integrated research (ICC 1996).

Despite the difficulty in creating accessible TEK, there have been opportunities for western science and TEK to join and create stronger, more holistic environmental research and understanding. The First Nations of British Columbia, Canada have been using TEK and community maps to record and communicate their historical land base and TEK to the Canadian government (Olive and Carruthers 1996). TEK has been advocated as a qualitative, intuitive, holistic, moral and spiritual science, which can contribute to the quantitative, rational, experimental, value-free, and mechanical western science (Berkes 1993). Many resource management issues are approached by conveniently fitting TEK *into* western science results. However, CTSI has approached the LED project from a different angle. They are using their TEK as a *basis* for pursuing western scientific studies.

CTSI families began noticing the decline in the lamprey harvest during the late 1980's. They appealed to the tribe to do a study on the lamprey populations and traditional harvesting practices, so that an important part of their cultural heritage would not be lost. By documenting the decline of the lamprey, the tribal members hoped that additional research would be started to determine the cause of the decline and initiate restoration measures (Downey et al. 1996).
CTSI responded by preparing SKWAKOL, a compilation of literature reviews, historical research, oral histories and recommendations for further research. The oral histories were the most important part of SKWAKOL because tribal members, who participated in lamprey harvesting and processing, shared their knowledge on the subject. In SKWAKOL, the elders shared their knowledge on the traditional hooking sites and practices, as well as the habitat requirements, ecology and populations of the lamprey. They described previous stream habitat conditions, ecological indicators of lamprey migration timing, and the best times and locations to "hook eel." Table 1 gives examples of standard questions and answers from these interviews with the tribal elders.

Table 1 Sample interview questions completed by CTSI.

Question	Answer	Interviewee
How far back do you remember that people fished on the Siletz?	As far back as I can remember. I think the first time I went to the river I was about three years old.	Pete Downey
Where were the traditional eel hooking grounds located on the Siletz?	Rock Creek, at the mouth of Rock Creek where the flat rock is, about a hundred feet up Rock Creek.	Everett Butler
How was the eels prepared after they were caught?	You had to clean them, take the backbone out. You could bake fresh or fry them. We used to soak them overnight in salt water, then hang them in the smoke house.	Gladys Muschamp
Can you describe what the eels look like? Color, size and general appearance?	Night eels are dark. They are longer. The sun eels are kind of a lighter color. The night eel is always longer, and they come in from the ocean, but the sun eel is always in the river.	Nellie Orton
What other types of animals did you observe that were abundant in and on the Siletz River?	There is such a thing as a river mussel in the river, but you can't chew it, it was really tough. There used to be a lot of crawfish as well, but I was told that they are coming back.	Vicki Ben

The information attained from the interviews was interpreted and transcribed into a GIS map by the CTSI interviewers (Figure 2). These interviews constitute valuable historical information for resource management, which would not otherwise available. Most importantly for the tribe, the information found in SKWAKOL led to the LED proposal and subsequent work in the Rock Creek watershed.

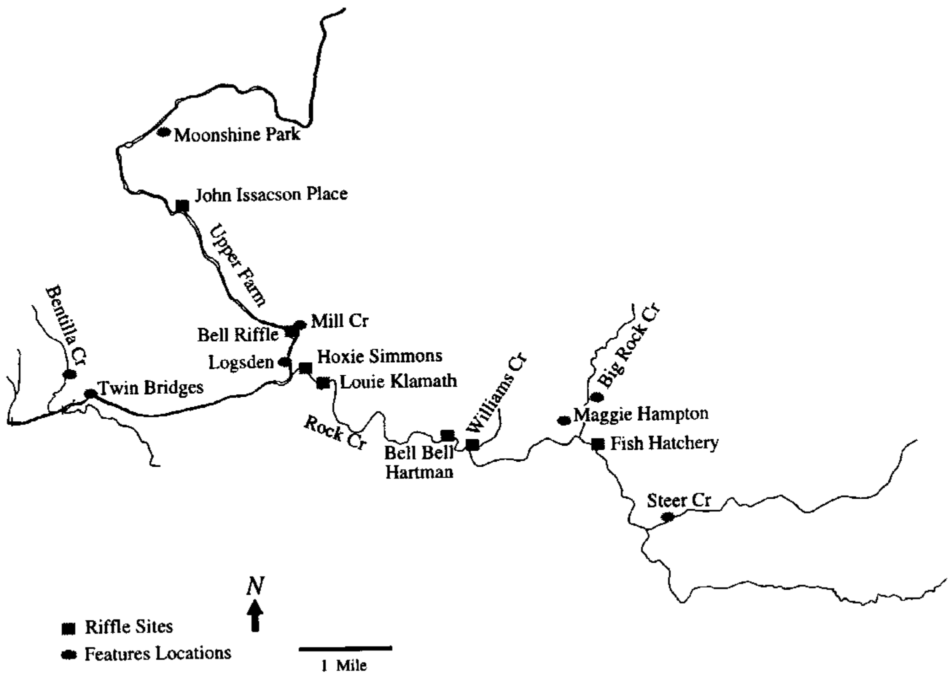


Figure 2: Cultural fishing sites on Rock Creek (from Downey et al. 1996)

Since the beginning of the LED project, the CTSI have applied TEK and an aquatic habitat GIS for sustaining lamprey populations. They have found a common goal with the Mid-Coast Watershed Council (a local citizen group interested in improving watershed health) in seeking to improve environmental conditions within area watersheds. CTSI collaboration with the watershed council has resulted in on-the-ground restoration activities. This is a classic case of people's knowledge about their environment influencing what they will do for it (Eythorsson 1993).

Methods

Background Research on Pacific Lamprey Biology and Ecology

As a preliminary step, a thorough review of available information on the biology and ecology of the Pacific lamprey was conducted. It was felt that this base knowledge was needed in order to utilize the GIS to determine suitable or desirable lamprey habitat for restoration and conservation purposes. Most of the information available on the Pacific lamprey came from the

Fraser River basin in Canada. Other information on lampreys was extrapolated from similar species.

Lampreys are primitive animals with highly specialized characteristics. The lamprey is an eel-like animal with an elongate, cylindrical shape, round in cross-section, but somewhat laterally compressed towards the dorsal end. It lacks jaws, internal ossification, scales and paired fins. As an adult, it is an external parasite of mid-water marine teleost fishes (Figure 3). Only nine lamprey species are believed to be parasitic. However, the lamprey is not parasitic its entire life. As a juvenile, it is a filter feeder, which requires a drastic metamorphosis to become a parasitic adult. Few vertebrate species undergo such a radical metamorphosis between the juvenile and adult stages. Parasitic lampreys can be anadromous or restricted to freshwater habitat and the mature adults are larger in size than the non-parasitic species (Hardisty and Potter 1971).

Figure 3: Line drawing of an adult lamprey from http://nearctica.com/nathist/fish/agnatha.htm

The Pacific lamprey is found primarily in the high latitude, colder regions of the Pacific Ocean (Hardisty and Potter 1971). This species exhibits an antitropical distribution. On the East coast of the north Pacific, the Pacific lamprey is found from Baja, California to the Aleutians. In many river systems, the lamprey distribution extends inland to the headwaters (Scott and Crossman 1973).

The Pacific lamprey larvae leave the nest as 7 mm ammocoetes after 1-3 weeks. These ammocoetes usually burrow into the soft substrate composed of mud, silt or sand found in eddies, backwaters, insides of bends, or behind obstructions (Figure 4; Hardisty and Potter 1971). Rivers considered rich in suspended organic matter suitable for the ammocoete and the limit to growth is on the capacity of the feeding mechanisms in the ammocoete, not the availability of food (Moore and Mallatt 1980).

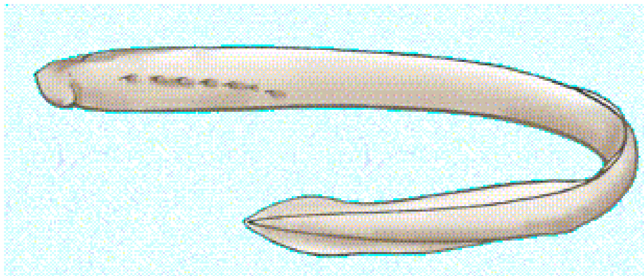


Figure 4: Line drawing of a lamprey ammocoete from http://www.earthsea.org/lampreys/LS-2-2-1-0.html

The juvenile life stages (eggs, larvae, ammocoete) of the Pacific lamprey are believed to last 4-6 years. At the end of that time, the ammocoetes undergo drastic metamorphosis to become parasitic adults. The metamorphosis includes physical external changes to allow parasitism as well as internal changes that allow osmoregulation. Lampreys complete their metamorphosis in fresh water while migrating to the marine environment. Richards and Beamish (1981) found most Pacific lamprey metamorphosing larvae in coarse substrate or gravel with higher levels of dissolved oxygen. Metamorphosis generally took 12 weeks. In Canada, the Pacific lamprey commences metamorphosis in July and begins downstream migration between September and December. Curiously, the peak downstream migration would often occur in March to May of the following year (Beamish and Levings 1991).

The jawless head of the adult has a large, nearly circular, buccal funnel fringed with concentric rows of sharp teeth, which opens ventrally. The skin is scaleless, but it is protected by slime produced by unicellular glands. The eyes are small with no eyelids. The Pacific lamprey has no true fins, but finfolds are present along the dorsal and ventral sides (Figure 3). The skin is dark grey, scaleless, and protected by a slimy substance. The median length of adults tends to be 27 inches (Hart 1973).

The average size of lamprey entering the marine environment is 13 cm (Beamish 1980). The parasitic adult lamprey prefers to consume body fluids rather than chunks of flesh and it tends to release its hold on its prey once it is satiated reduces the likely-hood of prey death. Prey mortality caused by the Pacific lamprey wounds is estimated at 1.6 to 1.8% (Beamish 1980). Off the West coast of Canada, pollock is the most common prey species. Sockeye and pink salmon have a high incidence of lamprey predation during the congregation for spawning runs. However, the Pacific lampreys do not remain attached during the spawning runs (Beamish 1980).

Currently, the estimate for the duration of the adult marine stage is 2.5 years (Beamish and Levings 1991). Pacific lampreys are anadromous, returning to their natal river to spawn. In Canada, the lampreys begin their spawning runs in April and have completed their migrations by September. Beamish and Levings (1991) found that the Pacific lamprey in the Fraser River system returned during the lowest river levels, usually around August. Stan van de Wetering (CTSI) found Pacific lamprey ammocoetes close to the headwaters of Little Rock Creek, which indicates the distance up the Rock Creek drainage adult lampreys swim to spawn (approximately 11 miles from the confluence of Rock Creek and the Siletz River). Adult lampreys appear to be particular about the location of the nest site. Other lamprey species, who build similar nests as Pacific lamprey gravel sizes of 0.9 - 5.1 cm, unidirectional water velocities of 0.5 - 1.5 m/s, water depths of 13 - 170 cm and temperatures ranging from 10 - 26 ^{O}C (Manion and Hanson 1980). In addition there must be sufficient gravel in the substrate to build the nest. Field observations by the author confirm that the Pacific lamprey in Rock Creek also build from gravel.

Much of the available information on Pacific lamprey was extrapolated from research done on other lamprey species or in other geographic areas, because little work has been done on the Pacific lamprey, and even less work done on the species in Oregon. This created challenges in data compilation, because assumptions had to be made concerning which information was most relevant. It was recommended that the CTSI to gather additional local biological and ecological information on their Pacific lamprey population. Since the LED report, CTSI has obtained funding and continued researching lamprey habitat preferences, distribution, spawning, temperature and sediment tolerances within the Rock Creek watershed (Stan van de Wetering, CTSI, pers. comm. 1999).

Stream Surveys

Since the CTSI works closely with federal, state and local agencies, as well as local organizations such as the Mid-Coast Watershed Council, it was decided to use aquatic habitat surveys produced by Oregon Department of Fish and Wildlife's (ODFW) Aquatic Inventory Project. ODFW field crews have surveyed streams throughout Oregon using well established protocols since 1990. An ODFW field crew surveyed Rock Creek in July 1994, and a Hire-the-Fishers crew surveyed Little Rock Creek in September 1995. Field crews walked the entire length of the stream recording data on channel and valley morphology, riparian characteristics and condition, and instream habitat. The habitat unit data includes parameters such as, substrate type, riparian vegetation, available wood structure, and river unit type and length (ODFW 1999). The details of the survey protocols are fully described in Methods for Stream Habitat Surveys (Moore et al. 1995). These survey data were entered by ODFW into a database file, which was made available for use in the LED project. Due to quality concerns, ODFW does not include the Little Rock Creek data into their statewide aquatic database.

Depending on the application of the resource management decisions, stream data can be categorized at the *stream* scale, the *reach* scale or the *river* unit scale. The river unit is the smallest descriptor of the geomorphic features in a given stream (e.g., pools, riffles) recorded by ODFW in their stream surveys. The reach scale is made by grouping the results of river units along an area of some functional characteristic (e.g., distance between tributaries, areas of similar land use, consistent valley or channel form). The stream scale combines all river or reach units contained within the entire stream. The river unit scale provides the most detailed information, because it is defined by the physical form of the stream bed and is not a combination of observations. ODFW used dynamic segmentation to link their data to arc stream coverages, but they worked at the reach scale on a 1:100,000 coverage (ODFW 1999). This scale, which has an effective resolution of 500 m (Goodchild 1993), is too small to use for the local resource management purposes desired by the CTSI (i.e., to choose critical restoration sites). In order to make a more adequate and useful product for CTSI, a river unit coverage was created with an effective resolution of 12 m, on a larger scale base map (1:24,000), based on the survey data provided by ODFW.

Dynamic Segmentation

Linear features such as streams present a challenge when associating multiple attributes. In the case of Rock Creek, there are many surveyed attributes that describe the riverine and riparian habitat. The arc-node structure represents the linear feature as an arc using a cartesian coordinate system and is one option for handling linear features and their attributes. Each arc is a set of point coordinates with nodes representing the ends. The attributes associated with the arc are stored within an arc attribute table and are referenced via the coordinate system (Figure 5). Since it is necessary to have one arc for each set of attributes, linear features with many or dynamic attributes do not work well in the arc-node structure, as the compilations of the single arc attribute tables become too large and cumbersome to manage with limited computing resources.

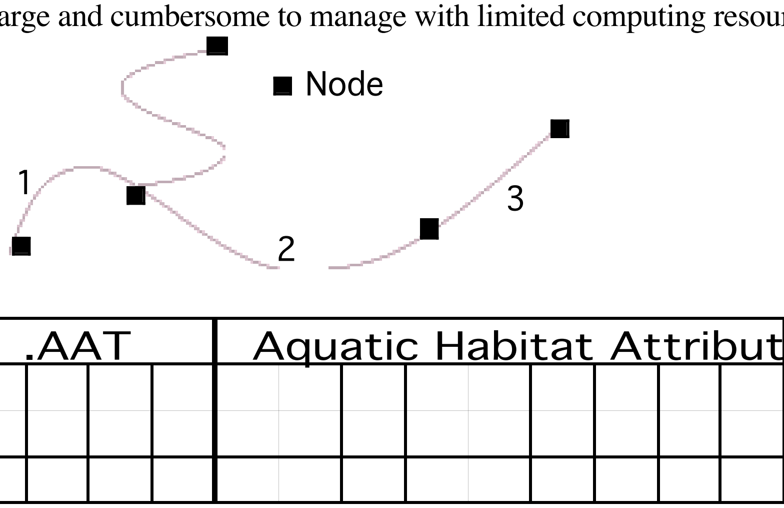


Figure 5: Schematic of the arc-node data structure and the resulting arc attribute table that could grow potentially very large frm assigning aquatic habitat data to individual arcs.

Dynamic segmentation, a second kind of structure for linear features is also comprised of arcs created with cartesian coordinates. However, the arcs have *routes* with an associated measurement system of relative distances from a specified starting location along a route. Attributes (events) are not stored in the arc attribute tables, but in a separate relational database making the storage, display, query and analysis distinct from the original arc coordinate system, and thus more efficient. Each attribute is associated to the route through the measurement system using to and from measurements (ESRI 1994, 1996); (Figure 6).

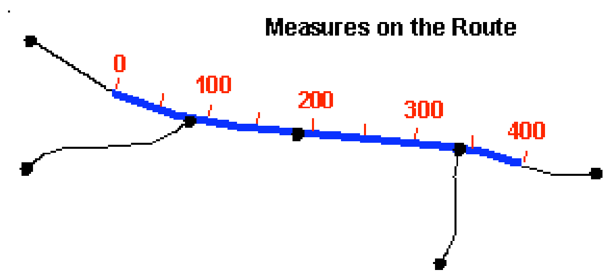


Figure 6: Schematic of dynamic segmentation.

The surveyed streams had 300-800 river units ranging from less than 0.1 m to over 250 m with the majority of the units less than 60 m. The high number of small, variable river units would produce very inefficient arc attribute tables, if the arc-node structure were used. Additionally, it would not be feasible to accurately create one arc for each river unit. Dynamic segmentation allowed the data to reside in a separate database table by creating relational measurements with the route system, thereby improving the accuracy, reducing the file size and allowing for quick and effective queries of the aquatic habitat attributes.

The primary users of the GIS are the CTSI natural resources department and the local watershed council, the Mid-Coast Watersheds Council. However, additional users could include local, state and federal agencies. The two primary users have desktop computers available and limited GIS resources and experience. Additionally, the CTSI desires the capability to query the habitat data based on habitat type (continuous features), as well as physical location on the streams (discrete points). Dynamic segmentation, which can be viewed and analyzed using ArcView provides this type of query flexibility.

There are three essential parts to dynamic segmentation: a georeferenced database, a calibration point coverage, and a clean arc coverage. The calibration point coverage is used to link the georeferenced database to the clean arc coverage. Having all of these items in order before beginning the dynamic segmentation process facilitates the linking process. The flow chart in figure 7 outlines the steps and processes needed to complete the dynamic segmentation using ArcTools within UNIX Arc/Info. More detail on each of the steps is provided below. Arc/Info commands and definitions, as well as my coverage and table names are listed in all capital letters.

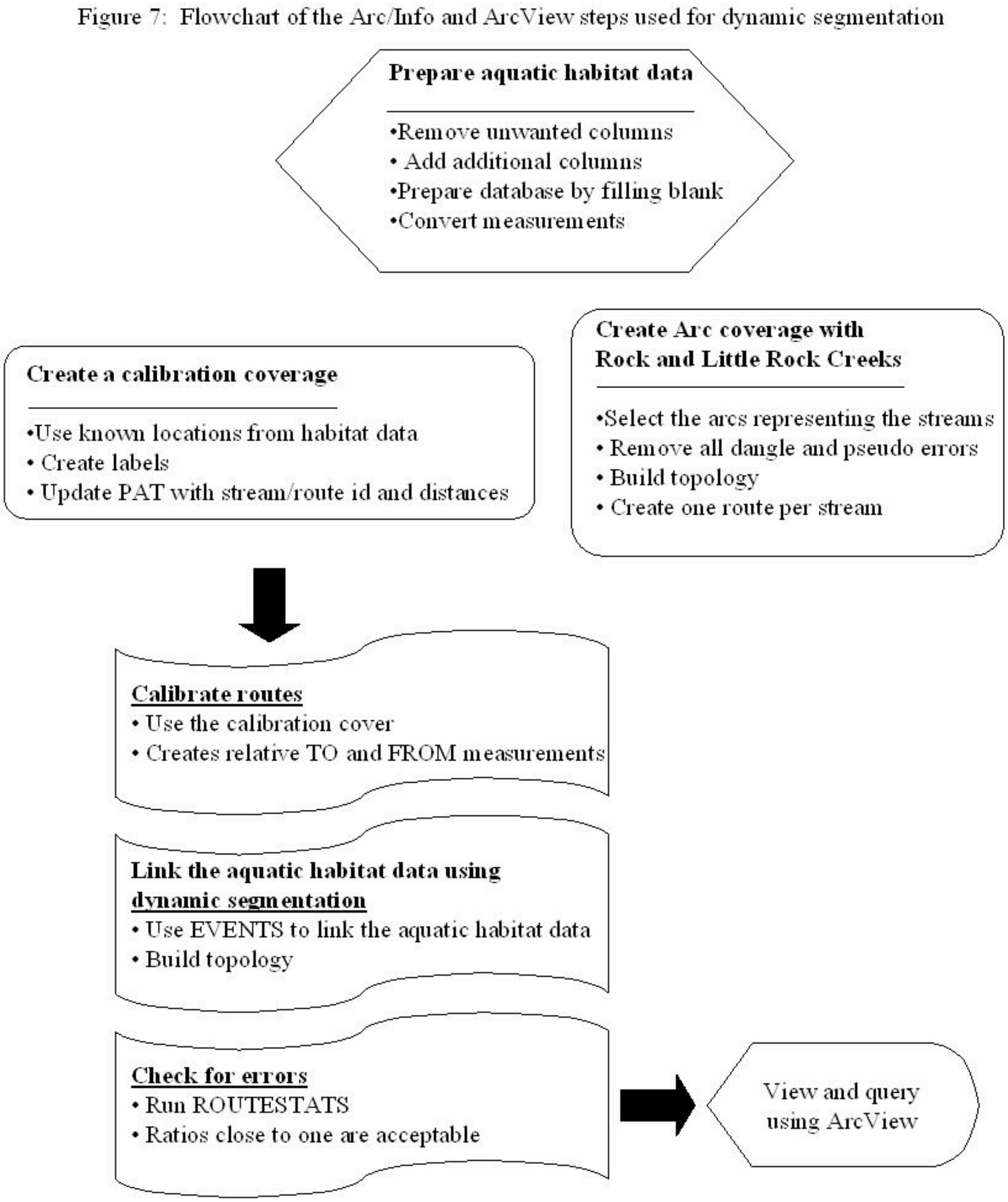


Figure 7: Flow chart of dynamic segmentation process.

i. Modification of the Aquatic Habitat Database

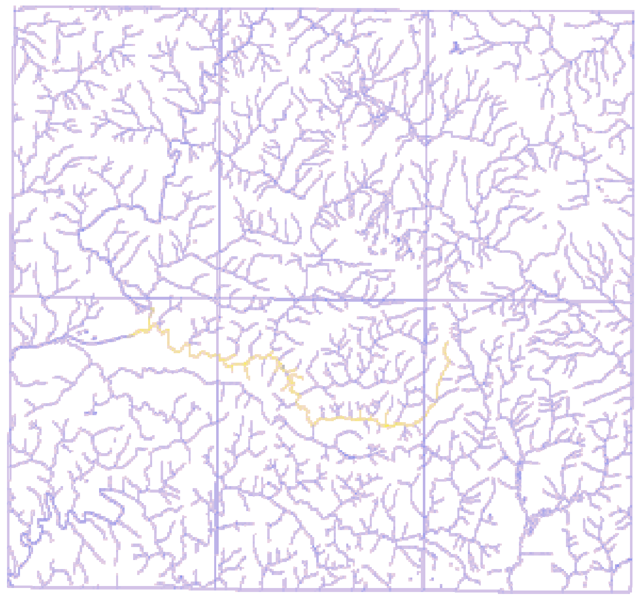
Some minor modifications of the aquatic habitat data from ODFW were necessary before it could be used for dynamic segmentation. Dynamic segmentation requires that the data are georeferenced to the start location of the route. The mouths of Rock Creek and Little Rock Creek were used as the starting reference points. The ODFW surveys contained measurements of each consecutive river unit. However, the ODFW data was recorded in meters and the arc coverage was in feet. All columns containing measurements of unit length only were converted to feet. "TODIST" and "FROMDIST" columns held the calculations needed to georeference the data to the routes. The "FROMDIST" column is the measurement from the mouth of the creek to the beginning of the river unit, while the "TODIST" column is the measurement from the mouth of the creek to the end of the river unit. A stream code was entered into the "STREAM_ID" column for each river unit. This code needs to coincide with the identification code created in the route and calibration coverages. Once the database was modified and found to be correct, it was imported into an INFO table (STRMDATA).

ii. Creating the Base Stream Coverage

The original arc coverage was provided by the CTSI and included every stream arc within Lincoln County (Table 3). The stream coverages were edited using the Arc edit pop-up menu in ArcTools. All streams not in the Rock Creek watershed were removed and a new coverage with only the watershed streams was created (ROCKWTR). Then, a separate coverage containing only stream arcs representing Rock Creek and Little Rock Creek was created (CREEKS; Figure 8). Pseudo-nodes were removed and all the arc directions were FLIPped to point in one direction (upstream). After these modifications, the final clean coverage was BUILT to re-create the correct topology.

Table 3 Description of the base coverage (arcs:streams) provided by CTSI

Creator	Atterbury Consultants, Inc.
Year	Base Map – 1991, Attribute table modified in 1996
Guidelines	Consistent with USGS and State Mapping Advisory Council
Attributes	Type, Name, and Size (of stream), plus Or_class (fish use)
Projection	State plane
Units	Feet
Datum	NAD 27
Fipszone	3601
Zone	5076



Original Coverage provided by CTSI (Rock and Little Rock Creeks are Highlighted)

All Creek in the Rock Creek Watershed (Rock and Little Rock Creeks are Highlighted)

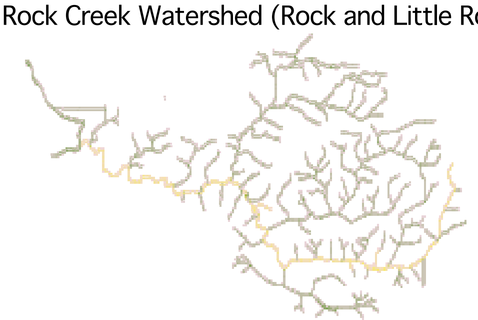


Figure 8: Progression from watershed coverage (ROCKWTR) to stream coverage (CREEKS).

iii. Creating the Calibration Point Coverage

The calibration coverage, although very simple, is one of the most important aspects of dynamic segmentation. Both the base stream coverage and the stream survey data had inherent, unknown spatial errors. These errors included those which developed during data collection (e.g., measuring the length of the stream accurately), determining location (e.g., global positioning system (GPS) error), and digitizing (e.g., human inaccuracy). The calibration coverage helped the joining of the coverage with the data by providing a point of reference for the smoothing of the spatial error. The necessary number of calibration points will vary with the amount of inherent error present and the size of the coverage area. It is always important to obtain evenly spaced, well-defined calibration points. The Rock Creek calibrations were done with eight calibration points for 17 miles (27 km) of stream.

The points used on the calibration coverage were known, locatable positions, both on the ground (listed within the surveys) and on the GIS coverage (Table 4). To create the calibration points that correspond with stream junctions, a new point coverage was created using the Label edit function in ArcTools. The backcover ROCKWTR displayed to locate the tributary junctions and create a correct label point. For more obscure locations like the fish hatchery steps, GPS coordinates were obtained from readings in the field and inputted into the coverage. The calibration .PAT was modified to contain a stream identification code and the distance (derived from the survey data) from the start location (Table 4). The backcover was changed to CREEKS and the label points were SNAPped to the backcover for route calibration (Figure 9).

Table 4 Calibration point information

Label ID	STREAM_ID	FROMDIST	On the ground location
1	65055	0.0	Mouth of Rock Creek (at Siletz River)
2	65055	19943.1	Junction of Rock Creek and Williams Creek
3	65055	32796.4	Siletz fish hatchery steps
4	65055	38727.3	End of Rock Creek at Little Rock Creek
5	65056	0.0	Mouth of Little Rock Creek (at Rock Creek)
6	65056	6894.2	Junction of Little Rock Creek and Brush Creek
7	65056	24774.5	Logsden road bridge flowing over Little Rock Creek
8	65056	42909.9	End of survey; steep topography

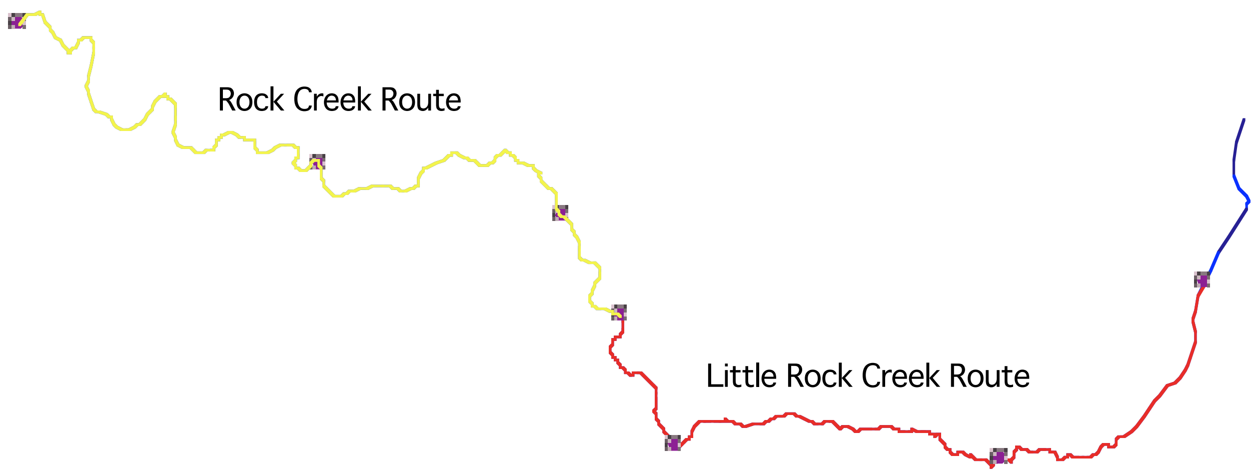


Figure 9: Rock Creek watershed coverage with calibration points.

iv. Creating the Routes and Sections

The routes were created on the stream coverage (CREEKS) and then the ROCKWTR and the CALIBPTS coverages were displayed for reference as backcovers. All the arcs in Rock Creek were selected and the command line window initiated. The MAKEROUTE command with subclass, STREAMS and route-id, 65055 was executed to create the route. The same procedure was followed for Little Rock Creek, except only the arcs, which included the survey route, were selected and the route-id was 65056. This process creates two new INFO tables: the route attribute table (.RAT) and the section attribute table (.SEC). When the route is created, the sections are equal to the selected arcs.

Since the survey did not encompass the entire stream, there were arcs present on the coverage after the survey distance (marked by the final calibration point). After the routes were created the edit feature was changed to route and the route edit functions in ArcTools were used to correct and measure the routes. Route 65055 (Rock Creek) was selected first, then all the sections were subselected. The REMEASURE function was used to create the route measurements of 0 to 38,727.3 feet (equal to the length of the aquatic survey). Next, route 65056 (Little Rock Creek) was selected. The aquatic survey did not conclude at the end of the last arc, so the last section of the route was subselected. The MOVEEND function was initiated and the end of the section was moved graphically to equal the end of the aquatic survey at the last calibration point. The route was REMEASUREed as 0 to 42,909.9 feet. Subselect all the sections in one route and use the table editor LIST function to make sure all the T-meas and F-meas are in consecutive order. Lastly, update the .RAT table by adding the STREAM_ID item. This is the same number as the route number and is needed in order to complete the dynamic segmentation with the aquatic data and the calibration table.

v. Calibrating the Route

CALIBRATEROUTES was used to smooth the errors between the arc coverage and the aquatic survey data. At the Arc command line the STREAMS route on the CREEKS arc coverage was calibrated with the CALIBPTS point coverage. The calibration split sections when necessary and performed partial measurement calibrations, in order to keep the entire route distance equal to the survey distance. LIST the records in the .SECSTREAMS INFO table to make sure the F-meas and T-meas are still consecutive.

vi. Linking the Stream Survey Data

An event table contains attributes, which describe portions of the routes. Data for creating an event were entered using the interactive EVENTSOURCE dialog box. STRMHAB served as the source name, STRMDATA was the INFO table, the relate was linear based on the STREAM_ID column in the route and data tables and FROMDIST and TODIST were the measurement items. EVENTSOURCE SAVE AQUAHAB created a usable event file (.EVA) for viewing the data. EVENTARC HABITAT built a dynamically segmented stream coverage from CREEKS with the arc coverage, route system and event source created a new coverage. It is necessary to BUILD the topology of the .EVA file.

vii. Error Detection

Before continuing, the error should be calculated using ROUTESTATS. This command calculated ratios of the measurements provided in the stream survey INFO coverage with the coverage unit measurements. Ratios close to one are preferable. Each project should decide on acceptable levels of error. Re-view the habitat, stream and calibration coverages to make sure that everything still matches up (i.e. calibration points still lie on the streams or streams no longer exist).

viii. Querying the Dynamic Segmentation Coverage

The new event coverage (HABITAT) was exported to an Arc/Info .e00 file and imported into ArcView, using Import71. A new view was started by opening the theme and the query builder tool allowed the user to customize queries based on the needs of the tribe GIS for aquatic habitat management (Figure 10).

Figure 10: Example of a potential resource management query related to Pacific lamprey habitat requirements on a small section of Little Rock Creek.

Conclusions: Aquatic Resource Management Potential

Traditionally a GIS has been used mostly as a descriptive mapping tool. However, the power of a GIS lies in its ability to perform spatial analysis and modeling, thus providing essential information to resource managers. With the dynamic segmentation data structure complete, CTSI has begun to build a powerful resource management tool. The next steps in building the GIS so that it can provide more holistic resource information involve adding more social and habitat data, and creating spatial and ecological models (Figure 11). Currently, most of the anticipated uses of the LED GIS are descriptive rather than prescriptive. Descriptive queries can produce summaries or inventories of the spatial data (Berry and Ripple 1996). However, prescriptive analyses (mathematical manipulation) of an expanded LED project GIS could provide resource managers valuable information for effective decisions. A vision for a more effective GIS, for the CTSI are outlined in this section.

Techniques such as single and multiple layer operations (e.g., Chou 1997) can help the CTSI answer descriptive questions regarding habitat availability and restoration suitability in Rock Creek with regards to the Pacific lamprey. Single layer operations are simple queries on the attributes. Understanding the ecological requirements of the Pacific lamprey is vital to creating effective queries. Using the overview of known lamprey habitat requirements, the CTSI can find stream units with certain characteristics. The queried attributes could be weighted or ranked based on their ecological importance. For example, gravel is critical to lamprey nesting success, so the model should have greater importance (weight) for that attribute (e.g. Berry 1995). Searching for potential restoration sites based on a set of criteria could also be accomplished through the same method. However, consideration of restoration sites would require more information regarding the surrounding land base. Overlays (multiple layer operations) of ownership, water rights and or land use could help narrow the site choices to those most likely to succeed. Overlays of the information from TEK (Figure 2) provide historical information on areas previously important to lampreys and the CTSI members. These operations are descriptive in nature, but still provide the resource manager with the necessary information for effective decisions.

Prescriptive analysis moves GIS from an inventory tool to an analytical tool. It allows the user to ask for more detailed quantitative information (Berry and Ripple 1996). Spatial modeling, point pattern analysis and network analysis (e.g., Chou 1997) are techniques used for spatial analysis. Historical change analysis and predictive models can be used in conjunction with the dynamic segmentation coverage and other land use coverages. Before the current LED GIS with dynamic segmentation can be used for these analyses, it is necessary to expand the GIS data layers to include terrestrial environmental data and historical data. For example, land use in Rock Creek includes active forestry. As patches of forest are clear cut, the runoff and sedimentation rates can affect the aquatic habitat. Knowing the future harvest plan, a resource manager can now quantitatively obtain information on the potential influence of the harvest on the aquatic habitat.

Errors in GIS are often overlooked because they are "hidden" from the end user. The real world is represented in the GIS by a spatial component (coordinates) and a tabular component (attributes) and errors can occur in both (Bolstad and Smith 1992). The accuracy of the GIS is limited by the measuring device used to collect the data (Goodchild 1993), as well as the methods for creating the GIS layers (Congalton and Green 1992). For the LED GIS, the base map was digitized by Atterbury Consultants, Inc. using methods consistent with the State Mapping Advisory Council guidelines. Since this map was digitized, errors could be produced by the natural mutations of the original paper map and human digitizing errors. The attribute data were collected in the field by field crews. Much of these data were estimated, however, actual measurements were taken every tenth unit for calibration (Moore et al. 1995). Depending on the types of analysis needed by the end user, the usefulness of the information could be limited, if the amount and types of error are not considered.

One of the largest problems, both with GIS and its use in resource management is that the GIS represents a static view of a dynamic system. It is an abstraction of a naturally variable ecological system. In this case, riverine systems are extremely variable at large and small spatial and temporal scales. The static representation of a dynamic system is another important consideration for the resource manager. For example, the data represent a static view of Rock

Creek (summer 1994) and Little Rock Creek (fall 1995). These data can only provide a snapshot of the actual stream habitat conditions. Resource managers in the Oregon Coast Range can expect stream conditions to change seasonally, especially with the swollen stream conditions experienced during the winter rains. The current stream conditions are probably quite altered due to a 100-year flooding event in the winter of 1996. However, conceptual and predictive models can increase the value of the information resource management by providing potential stream conditions.

Information is the key to effective management decisions. GIS can provide resource managers with descriptive and prescriptive information. Using the LED GIS, resource managers can search for suitable habitat restoration sites and, with additional data layers, they can predict potential changes and analyze historical change. GIS does not produce resource management decisions. It merely enhances the information available. It is still necessary for managers to combine the GIS information with their "on the ground" knowledge of the ecological system and their understanding of the error included in the GIS to produce sound resource management decisions.

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